Small Business Innovation Research/Small Business Tech Transfer

Extraterrestrial Metals Processing, Phase II

Completed Technology Project (2017 - 2019)

Project Introduction

The Extraterrestrial Metals Processing (EMP) system produces iron, silicon, and light metals from Mars, Moon, or asteroid resources in support of advanced human space exploration. Refractory oxides and minor constituents such as sulfur, phosphorus, and alkaline earth oxides are also generated as byproducts and can be used for the refining of finished goods, thereby further reducing dependence on Earth-based consumables. Iron is produced via reduction of oxides by hydrogen or carbon monoxide. Silicon, ferrosilicon, and high-purity fumed silicon monoxide are generated via carbothermal reduction of silica-containing resources. Reductants are generated using established ISRU-related technologies including electrolysis, the reverse water gas shift reaction, the Boudouard carbon deposition reaction, and combinations thereof. During Phase I, magnesium metal was successfully produced via silicothermic reduction. Alternative light metal reduction methods will be evaluated and compared to the baseline silicothermic reduction of magnesium oxide for structural applications, replacement parts, and manufacturing hardware on Mars. A high-quality fumed silicon monoxide product can be further oxidized and used for production of clear glass. Upon reduction with carbon, SiO can also be used to make high purity silicon for the production of semiconductor materials using doping agents such as phosphorus. The Phase II effort will expand on the findings of the Phase I work with demonstration of an end-to-end system to produce iron and steel at a rate on the order of one kilogram per day. Example parts will be made using casting, sintering, or advanced manufacturing methods. In parallel with the demonstration of end-to-end iron production during Phase II, light metals manufacturing methods evaluated during Phase I will be further refined. Small-scale production of light metals will be demonstrated during Phase II.

Anticipated Benefits

The primary application of EMP is for production of iron, silicon, and light metals as well as refractory metal oxides and byproducts including phosphorus and oxygen from Mars, Moon, or asteroid resources for manufacturing in support of advanced human space exploration. The EMP product suite includes many useful materials that will expand exploration and colonization capabilities while substantially reducing the costs and risks of bringing supplies from Earth. Many EMP product streams are suitable for use in advanced casting or additive manufacturing methods to allow for efficient use of resources.One potential terrestrial EMP application is the production of high-grade silicon metal or ferrosilicon. The hydrogen-enhanced carbon monoxide disproportionation method employed in the EMP system for reductant production enables high rates of carbon deposition onto pure silica in the absence of a metal catalyst. Direct carbon deposition from CO generated during carbothermal reduction integrated with RWGS-electrolysis modules would reduce the purchase of carbon for the process while significantly reducing overall carbon emissions compared to current practice. The carbon

Extraterrestrial Metals Processing, Phase II Briefing Chart Image

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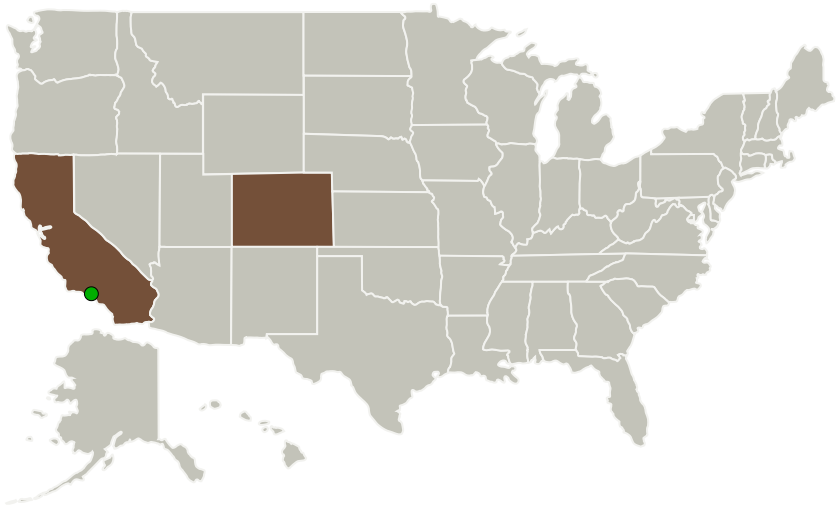
deposited by this method would be of very high purity. Such processing would have particular application and potential for manufacturing cost savings if carbon emissions become regulated. In a complete closed-loop system including a reverse water gas shift and electrolysis unit, silicon or ferrosilicon manufacturing could be accomplished with virtually no carbon emissions. The EMP techniques have additional potential for the processing of lower-grade ores and feed stocks including other process residues and wastes. As higher-grade ores on Earth are more-difficult to find and mine, feed costs for existing technologies rise. The EMP can help to reduce overall processing costs by enabling the use of non-conventional feed stocks and the non-conventional metal oxide reduction techniques proposed for the Phase II effort.

Primary U.S. Work Locations and Key Partners



Organizations Performing Work	Role	Type	Location
Pioneer Astronautics	Lead Organization	Industry Historically Underutilized Business Zones (HUBZones)	Lakewood, Colorado
Jet Propulsion Laboratory(JPL)	Supporting Organization	NASA Center	Pasadena, California

Organizational Responsibility

Responsible Mission Directorate:

Space Technology Mission Directorate (STMD)

Lead Organization:

Pioneer Astronautics

Responsible Program:

Small Business Innovation Research/Small Business Tech Transfer

Project Management

Program Director:

Jason L Kessler

Program Manager:

Carlos Torrez

Project Managers:

Carol R Lewis
Robert A Jones

Principal Investigator:

Mark Berggren

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Primary U.S. Work Locations	
California	Colorado

Project Transitions

April 2017: Project Start

April 2019: Closed out

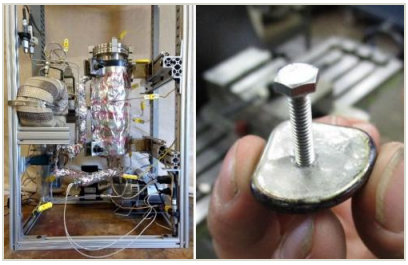
Closeout Documentation:
- Final Summary Chart*(https://techport.nasa.gov/file/140976)*

April 2019: Closed out

Closeout Documentation:
- Final Summary Chart PDF*(https://techport.nasa.gov/file/140977)*

Images

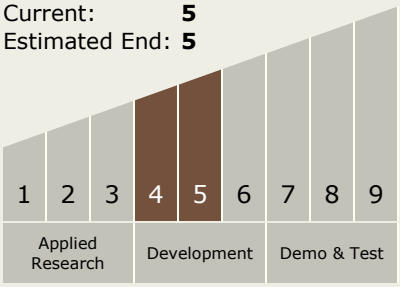
Briefing Chart Image
Extraterrestrial Metals Processing, Phase II Briefing Chart Image *(https://techport.nasa.gov/image/135811)*



Final Summary Chart Image
Extraterrestrial Metals Processing, Phase II
(https://techport.nasa.gov/image/131489)

Technology Maturity (TRL)

Start: **4**
Current: **5**
Estimated End: **5**



Target Destinations

The Sun, Earth, The Moon, Mars, Others Inside the Solar System, Outside the Solar System